DIS 2011

XIX International Workshop on Deep Inelastic Scattering and Related Subjects

April 11-

Marriott at Ci

INFN

ZEUS

Inelastic J/ψ photoproduction at HERA

A. Bertolin (INFN - Padova) on behalf of the ZEUS Collaboration
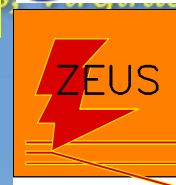
Outline:

- HERA and ZEUS

- charmonium production at HERA

- recent charmonium measurements by ZEUS:

    - *J/ψ* helicity parameters (reminder)

    - new *J/ψ* double differential cross section measurements:

        - ZEUS measurements and comparison with QCD predictions
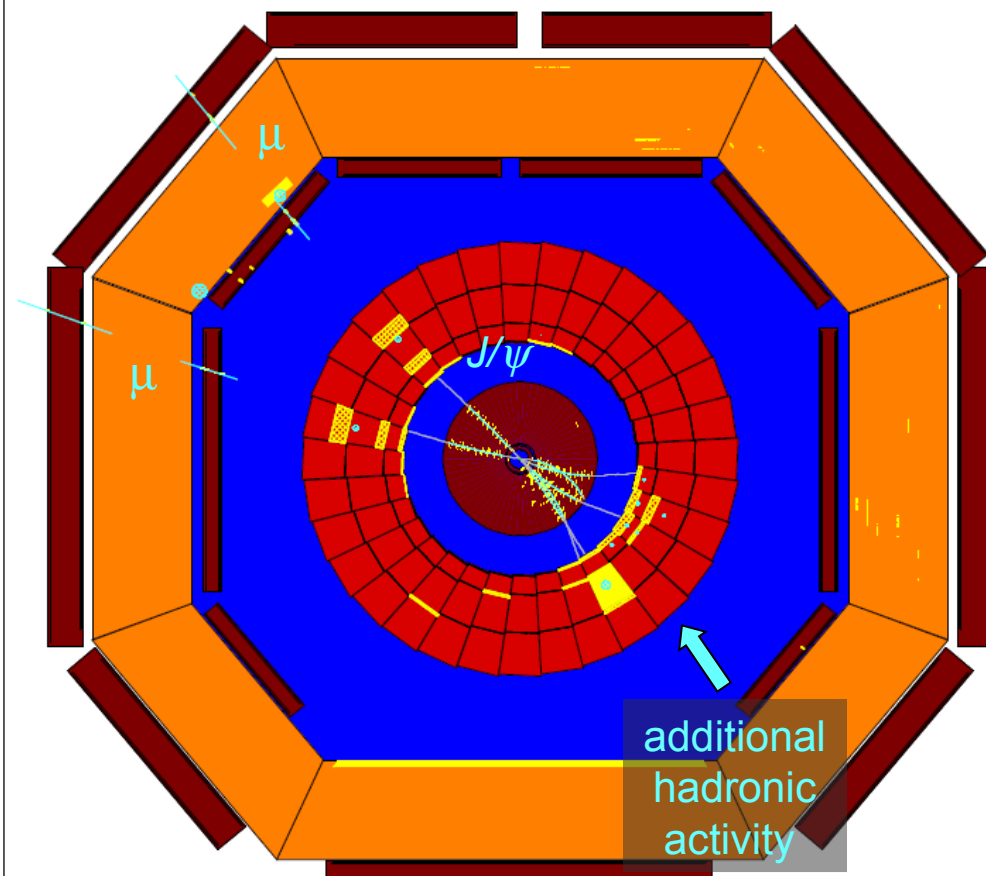
        - comparison with H1

- conclusions

• HERA was an *e p* collider at high CMS energy (this was like having an about 50 TeV *e* beam on fixed target)

• ZEUS was a large multipurpose experiment

• running ended mid 2007, will see results integrating all the data taken since 1996: 11 years of activity and 468 pb^{-1} of integrated luminosity
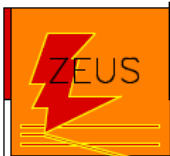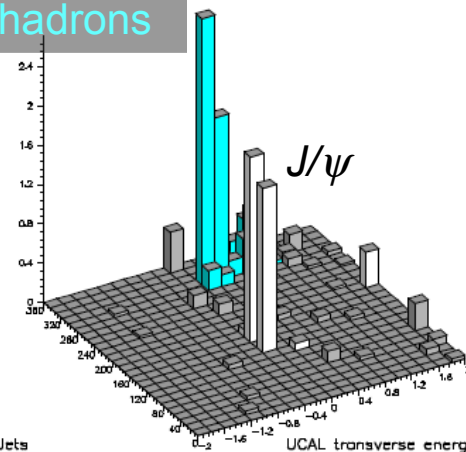
inelastic J/ψ event as seen in the ZEUS detector

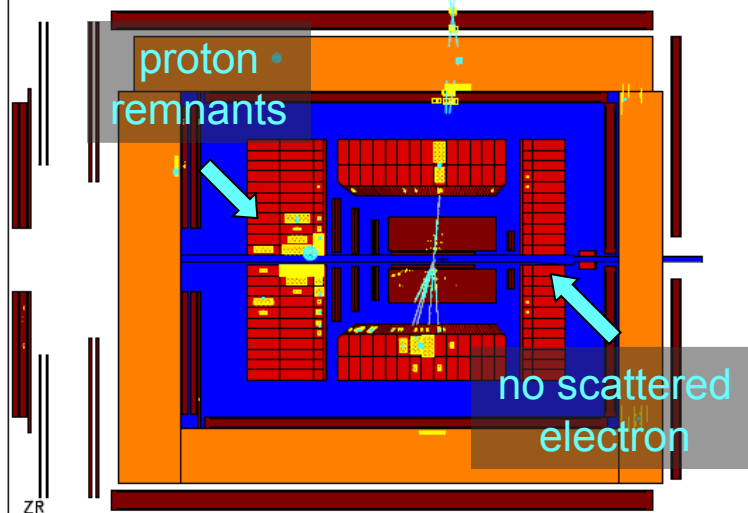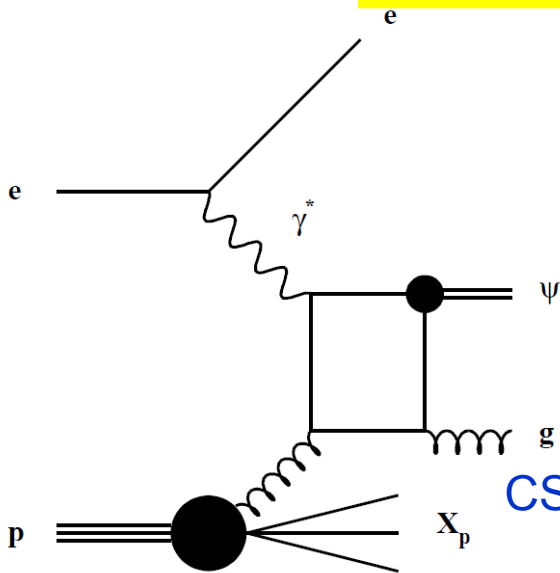- proton remnant + additional hadronic activity: inelastic event
- no scattered electron: photoproduction regime

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direct γ
CO model (cc q.n. ≠ J/ψ q.n.)
this particular diagram
0.2 < z < 0.9

direct γ
CS model (cc q.n. = J/ψ q.n.)
0.2 < z < 0.9
p-rest frame: z = E(ψ)/E(γ*)
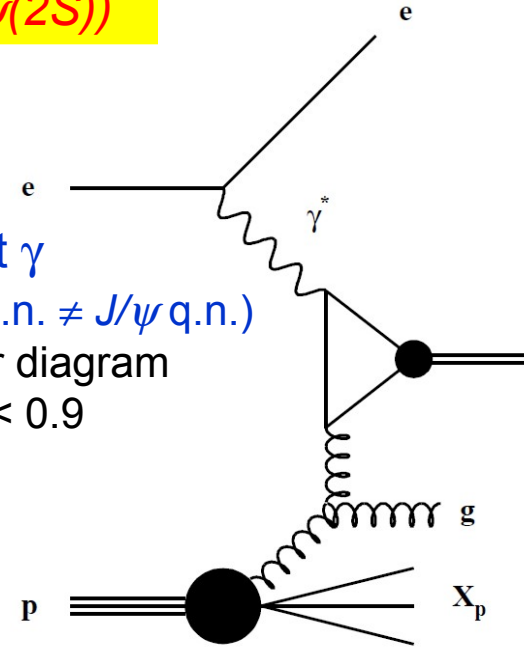
other contributions to the signal (decreasing size):

• ψ(2S) → J/ψ (→ μ μ) X decays

• J/ψ from B meson decays

• J/ψ from resolved photon processes
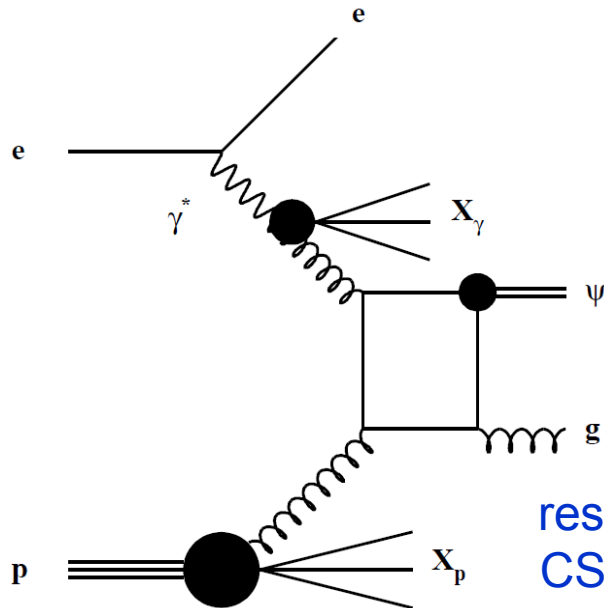
resolved γ
CS model
z < 0.2

main background source:

• J/ψ from proton diffractive dissociation

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• inelastic ψ(2S) production:

● ZEUS 96-97
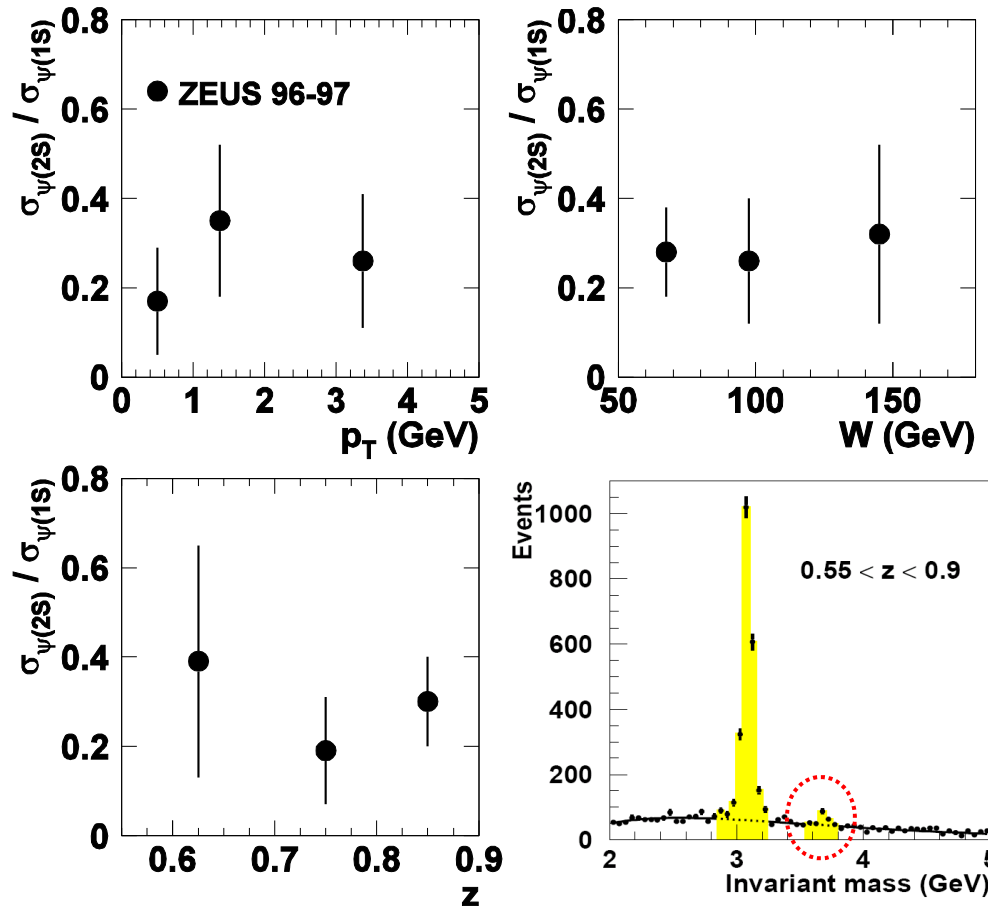
• < 1/10 of the total available luminosity

• ψ(2S) to ψ(1S) cross section ratio consistent with being flat, 0.33 ± 0.10 (stat), sys negligible (cancel when taking the cross section ratio)

• via $\psi(2S) \to J/\psi (\to \mu\mu) X$ this results in a 15 % increase of the J/ψ cross section

NOT subtracted

not possible experimentally … would need an inclusive reconstruction of the decay $\psi(2S) \to J/\psi (\to \mu\mu) X$

0.55 < z < 0.9

• charmonium from B meson decays: B production well tested at HERA, much smaller B cross section than at hadron colliders: overall < 1.7 % of the J/ψ are from B meson decays, < 9 % at low z

NOT subtracted

• J/ψ from resolved γ processes (including $\chi_c \rightarrow J/\psi \gamma$): not well know in PHP, LO cross section is tiny at HERA: overall < 0.5 %, < 4 % at low z

NOT subtracted

main background

• charmonium from proton diffractive dissociation:

J/ψ produced at z > 0.9 but some are reconstructed with z < 0.9

can observe the proton remnants but have only a little chance of observing any additional hadronic activity (no color connection between the J/ψ and X_p)

2 μ + proton remnants + $\geq$ 1 track with p_t > 0.125 and $|\eta|$ < 1.75 $\Rightarrow$ very strong suppression

(min. p_t(track) << min. pt(J/ψ) > 1 GeV $\Rightarrow$ safe requirement)

the remaining contribution is obtained by fitting the measured z distribution using the HERWIG MC for the signal and the EPSOFT MC for the background

overall: 6.9 % contribution, < 20 % for 0.75 < z < 0.9 $\Rightarrow$ strongly peaked at high z

subtracted

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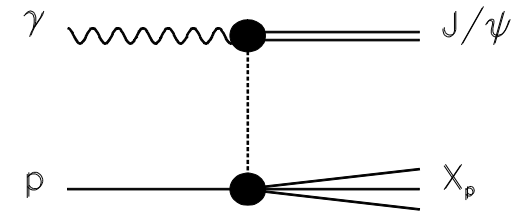
reminder: elastic charmonimum: gone asking for the proton remnants
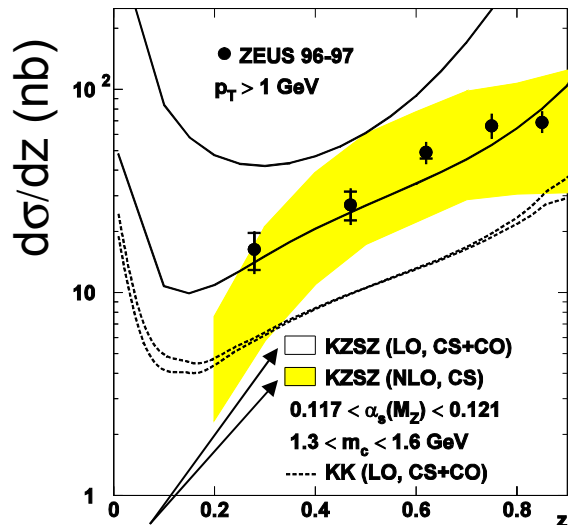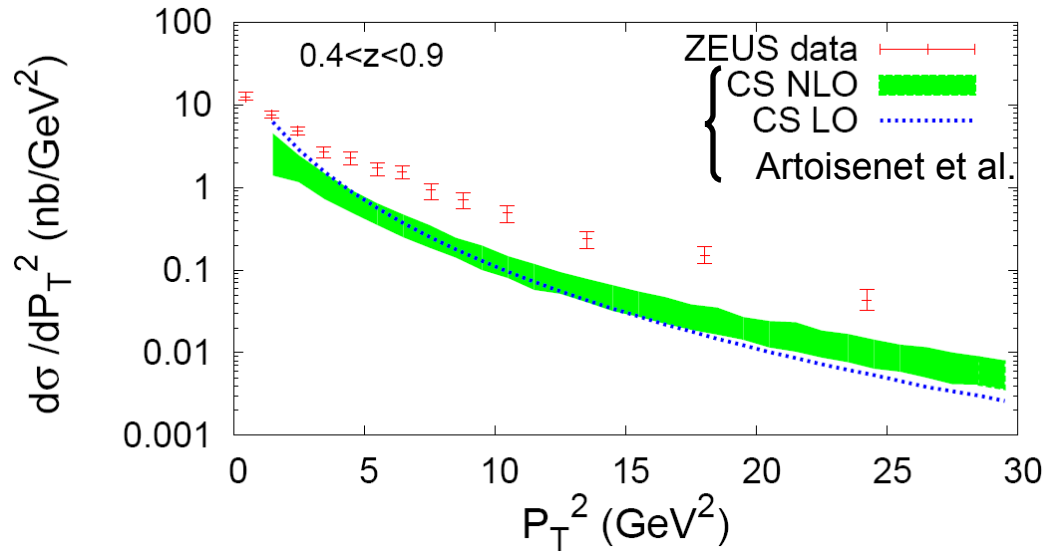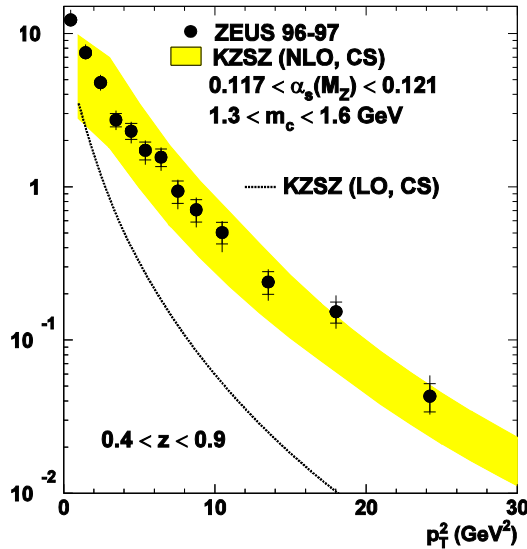
Kramer et al.

• same ZEUS data points are shown in the two upper plots

• old cross section measurements based on less than 1/10 of the available luminosity

• inelasticity distribution is different for CS and CS+CO … but theory has large uncertainties …

as experimentalist our goal is to provide to the theorist the best possible measurements hoping that theory will improve

$\Rightarrow$ double differential cross section in z and p_t^2 using the full available statistics

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recent J/ψ helicity measurements at HERA

ZEUS 468 pb^{-1}
0.4 < z < 1

LO CS
NLO CS
LO k$_T$ (JB)
LO k$_T$ (dGVR)
LO CS+CO

p_T (GeV)

LO CS
NLO CS
LO k$_T$ (JB)
LO k$_T$ (dGVR)
LO CS+CO

ZEUS 468 pb^{-1}
p_T > 1 GeV

z
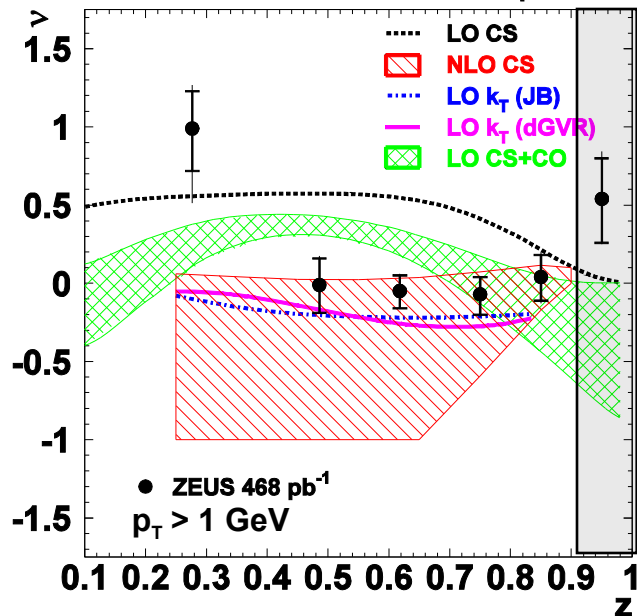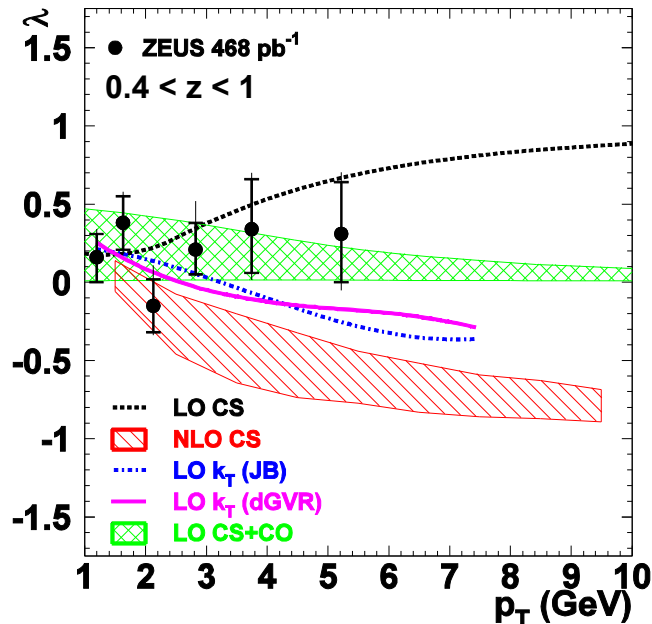
• LO CS and NLO CS predictions have opposite sign … we initially thought NLO corrections would be small …

• LO k$_T$ CS has the same sign of NLO, parton transverse momentum, k$_T$, mimics NLO terms

• LO CS+CO is flat

• data are consistent with being flat in the probed p$_T$ range

• diffractive background mostly at low p$_T$, analysis redone for z < 0.9, effects in the sys. errors

• LO CS does not describe the data, positive

• NLO CS has large uncertainties … negative … p$_T$ > 1 GeV may be not enough …

• LO k$_T$ CS fine … may be except at low z

• LO CS+CO does not describe the data, positive

• diffractive background decreases strongly with z

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JHEP 12 (2009) 007

all available data used
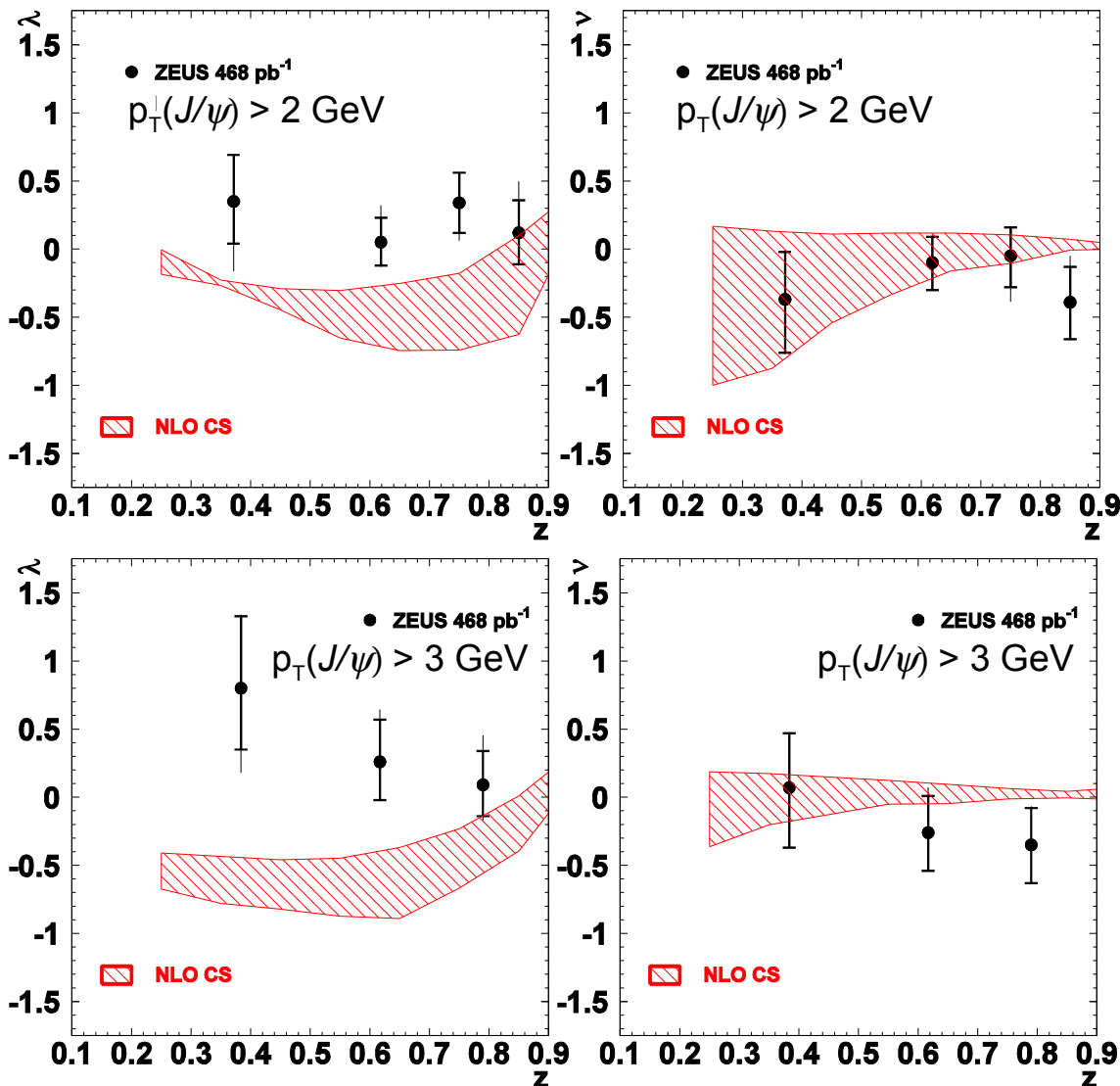
NLO predictions for:

• $p_T(J/\psi) > 2$ GeV

• $p_T(J/\psi) > 3$ GeV

NLO calculation has reduced uncertainties … unlikely experimental errors grow … and the agreement between NLO and data does not really improve …

p_t^2 range: from 1 to 100 GeV^2, 9 bins

z range: from 0.1 to 0.9, 5 bins

ZEUS
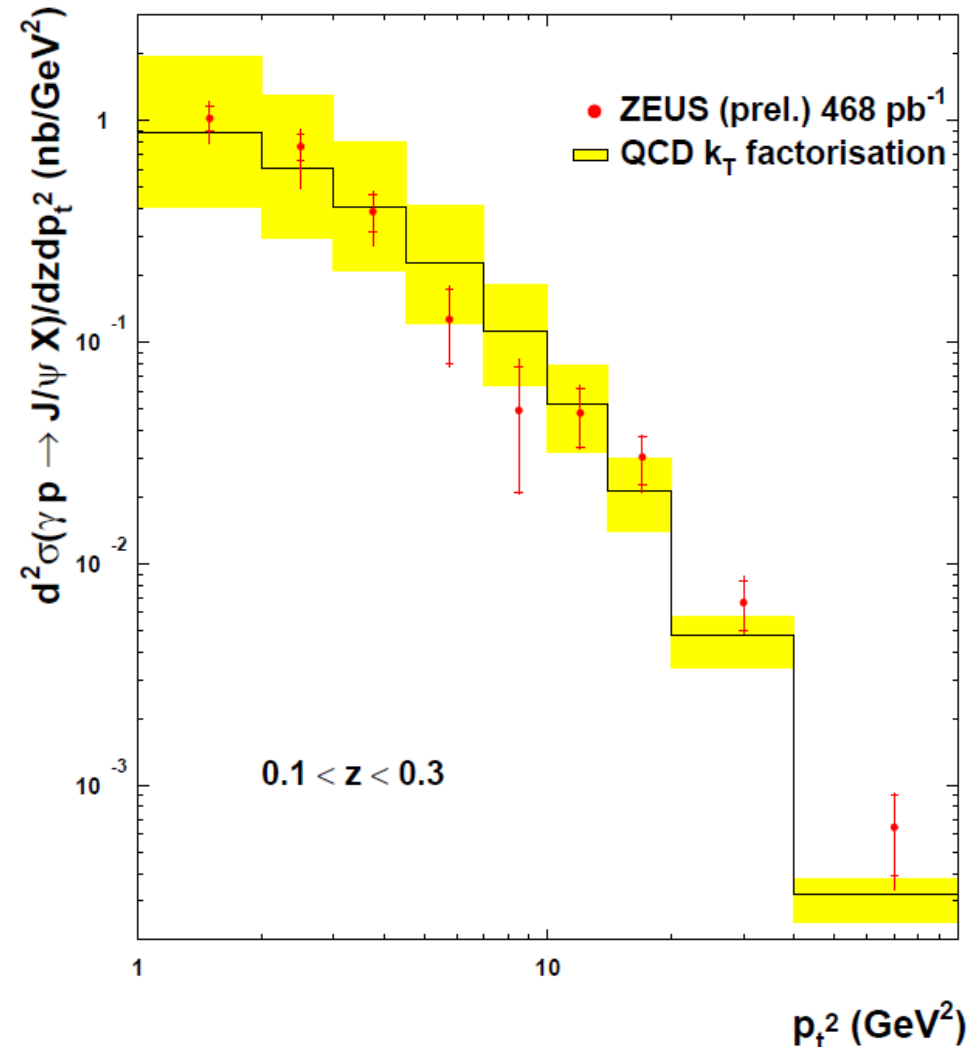
- 468 pb^{-1}: all ZEUS data are being used

- inner (outer) error bar: stat (stat⊕sys)

- QCD k_T factorization:

m_C = 1.5 GeV, $\alpha_s(M_z^2)$ = 0.1232

$\mu_R = \xi (m_\psi^2 + p_t^2)^{0.5}$, $\mu_F = \xi$ (shat+Q_T^2)

central value ξ = 1, band ξ = 1/2 – 2

- stat are dominant except at low p_t^2

- data are significantly more precise that theory except at high p_t^2

- good agreement between data and theory

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- stat still dominant

- sys dominant except at high p_t^2

- data are significantly more precise that theory except at high p_t^2

- good agreement between data and theory

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ZEUS

- ZEUS (prel.) 468 pb^{-1}
- QCD k_T factorisation

$0.6 < z < 0.75$

$d^2\sigma(\gamma p \rightarrow J/\psi\, X)/dzdp_t^2$ (nb/GeV^2)

p_t^2 (GeV^2)

ZEUS

- ZEUS (prel.) 468 pb^{-1}
- QCD k_T factorisation

$0.75 < z < 0.9$

$d^2\sigma(\gamma p \rightarrow J/\psi\, X)/dzdp_t^2$ (nb/GeV^2)

p_t^2 (GeV^2)

- sys are dominant except at high p_t^2

- data are significantly more precise that theory

- good agreement between data and theory

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ZEUS
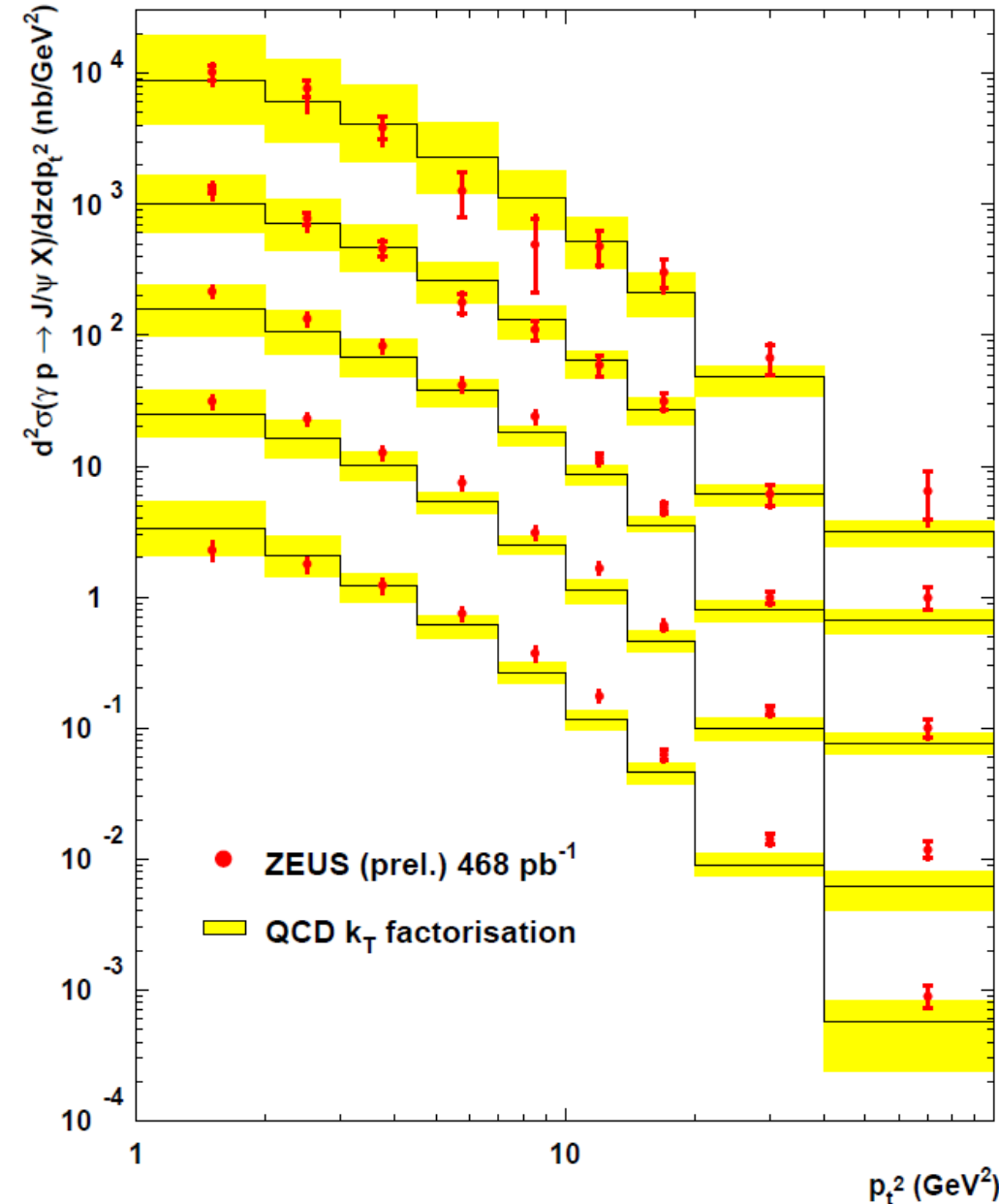
- precise set of measurements spanning a wide range in z and p_t^2
- do not observe strong variations of the p_t^2 shape spanning the probed z range … as if one could factor out, $f(z)g(p_t^2)$, the z and p_t^2 dependence
- can the theorist accept the challenge ?
- the QCD k_T factorization group did, a good description of the data is achieved

$0.1 < z < 0.3$, x 1E+4

$0.3 < z < 0.45$, x 1E+3

$0.45 < z < 0.6$, x 1E+2

$0.6 < z < 0.75$, x 1E+1

$0.75 < z < 0.9$, x 1E+0

ZEUS (prel.) 468 pb^{-1}

QCD k_T factorisation

$d^2\sigma(\gamma p \rightarrow J/\psi X)/dzdp_t^2$ (nb/GeV^2)

p_t^2 (GeV^2)

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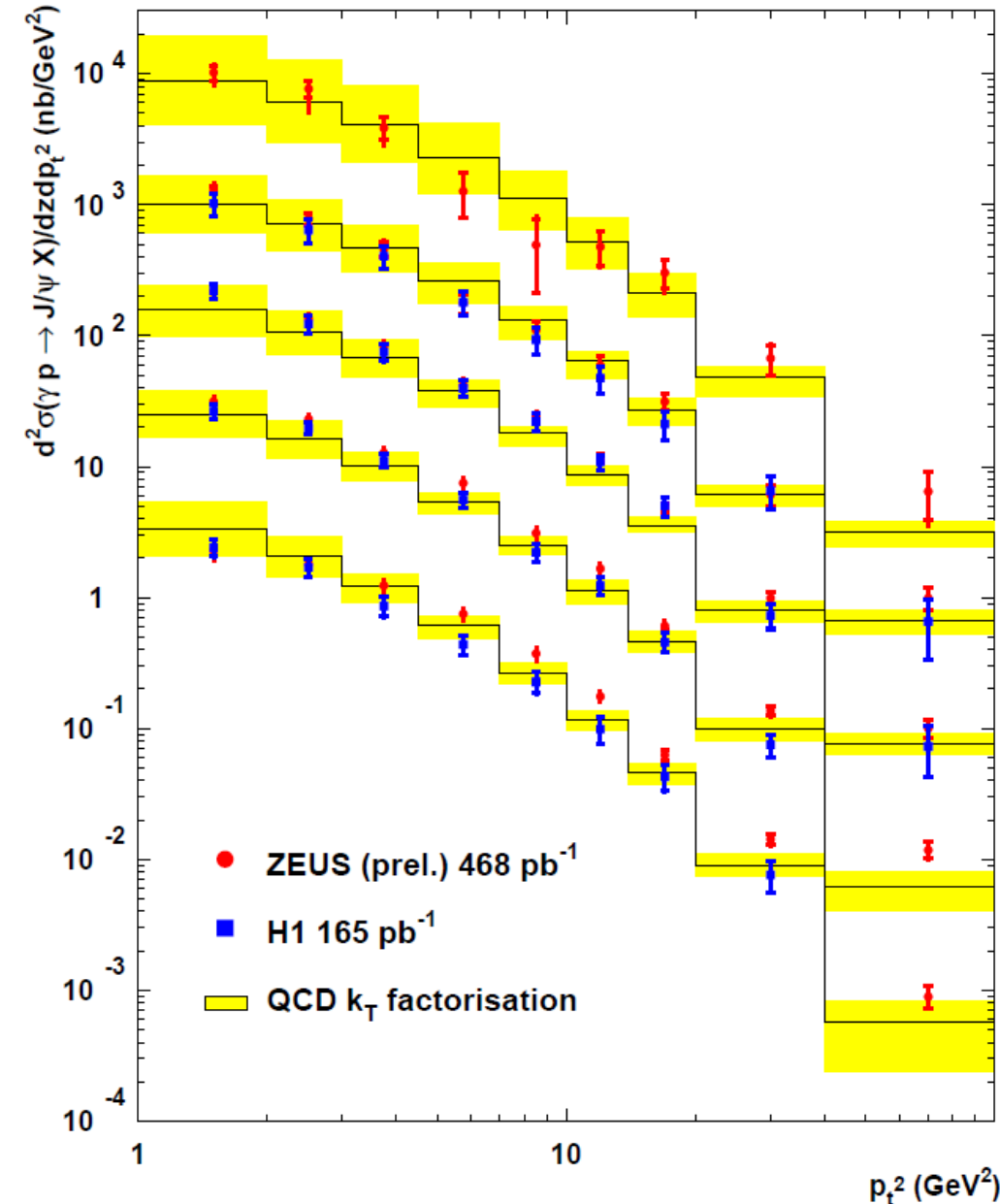
ZEUS

comparison with the published H1 data:

• *plots shown for the first time at this conference*

• ZEUS results is based on 2.8 more statistic

• this explain the wider range in z (and p_t^2 at high z)

• data are generally in good agreement

the range 0.75 < z < 0.9 p_t^2 > 3 GeV² will be investigated carefully

Legend in figure:
- ZEUS (prel.) 468 pb⁻¹
- H1 165 pb⁻¹
- QCD k_T factorisation

Curve labels:
0.1 < z < 0.3, x 1E+4
0.3 < z < 0.45, x 1E+3
0.45 < z < 0.6, x 1E+2
0.6 < z < 0.75, x 1E+1
0.75 < z < 0.9, x 1E+0

Axis labels:
$d^2\sigma(\gamma p \to J/\psi X)/dzdp_t^2$ (nb/GeV²)
p_t^2 (GeV²)

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conclusions

• new ZEUS double differential inelastic J/ψ cross section measurements are now available

• full luminosity is being used

• data are limited by systematic except at low z and high p_t^2

• the ZEUS data are compared to the H1 measurements: the data sets are generally in good agreement

• data are compared to a QCD k_T prediction: within the present uncertainties of this prediction an encouraging agreement is found

• at the end of the HERA physics program precise double differential inelastic J/ψ cross section measurements will be left in heritage to the quarkonium community … meanwhile we hope that the QCD predictions will be refined more and more at that, at some point in the future, a more stringent comparison between data and measurements will be possible

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… backup slides …

3 Numerical results

We now are in a position to present our numerical results. First we describe our input and the kinematic conditions. After we fixed the unintegrated gluon distributions, the cross sections (3) and (4) depend on the renormalization and factorization scales μ_R and μ_F. In the numerical calculations we set $\mu_R = \xi\sqrt{m_\psi^2 + \mathbf{p}_{\psi T}^2}$, $\mu_F = \xi\sqrt{\hat{s} + \mathbf{Q}_T^2}$, where $\mathbf{Q}_T$ is the transverse momentum of initial off-shell gluon or gluon pair (in the case of resolved photon production). In order to

estimate the theoretical uncertainties of our calculations we vary the scale parameter ξ between 1/2 and 2 about the default value $\xi = 1$. The sensitivity of the predictions to the charmed quark mass has been investigated previously in [20, 21]. Here we set $m_c = 1.5$ GeV and use the LO formula for the coupling constant $\alpha_s(\mu^2)$ with $n_f = 4$ quark flavours at $\Lambda_{\mathrm{QCD}} = 200$ MeV, such that $\alpha_s(M_Z^2) = 0.1232$. Note that we apply another value $\Lambda_{\mathrm{QCD}} = 220$ MeV for the CCFM-evolved gluon densities (see discussion in Sect. 3.1). Finally, the J/ψ wave function at the origin of coordinate space is taken to be equal to $|\Psi(0)|^2 = 0.0876$ GeV^3 [31].

❑ simplest example first: assume that all J/ψ originate from the spin-less state $^1S_0^{(8)}$ then the *J/ψ* will be unpolarized and the μ decay angular distributions will be the ones of a state with spin 1

❑ in general the μ decay angular distribution in the *J/ψ* rest frame is parameterized as:

$d^2\sigma/d\Omega dy \propto 1 + \lambda(y) \cos^2\theta + \mu(y) \sin 2\theta \cos\varphi + \frac{1}{2} \nu(y) \sin^2\theta \cos 2\varphi$

where y stands for a set of variables, z and $p_T(J/\psi)$ are good candidates

• λ, μ, ν are related to the different CS + CO matrix elements involved

• λ, μ, ν depend on the definition of a coordinate system

main advantage:

"Since the decay angular distribution parameters are normalized, the dependence on parameters that affect the absolute normalization of cross sections, such as m_c, α_s, μ_R, μ_F and parton distribution, cancels to a large extent and does not constitute a significant uncertainty"

⇒ a source of theoretical uncertainties is gone

main disadvantage:

for every y bin we have to fit a distribution

⇒ unlikely requires large statistics

even using all the available luminosity we can not perform a double differential analysis without getting very large errors

but we can integrate the "helicity master formula"

• in φ

$1/\sigma \, d^2\sigma/d\cos\theta \, dy \propto 1 + \lambda(y) \cos^2\theta$

• in $\cos\theta$

$1/\sigma \, d^2\sigma/d\varphi \, dy \propto 1 + 1/3 \, \lambda(y) + 1/3 \, \nu(y) \cos 2\varphi$

can measure with good accuracy λ and ν (two out of three helicity parameters)

which frame ? frame accessible experimentally using photoproduction events: target frame
❑ z axis (quantization axis): along the opposite of the incoming proton direction in the *J/ψ* rest frame
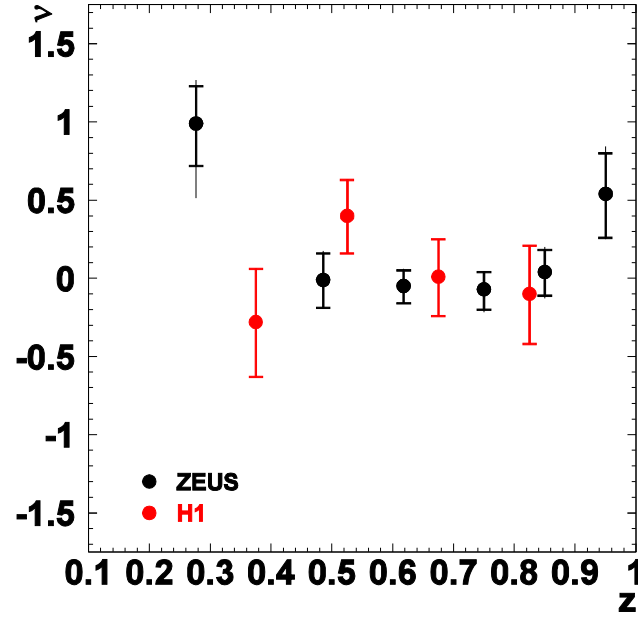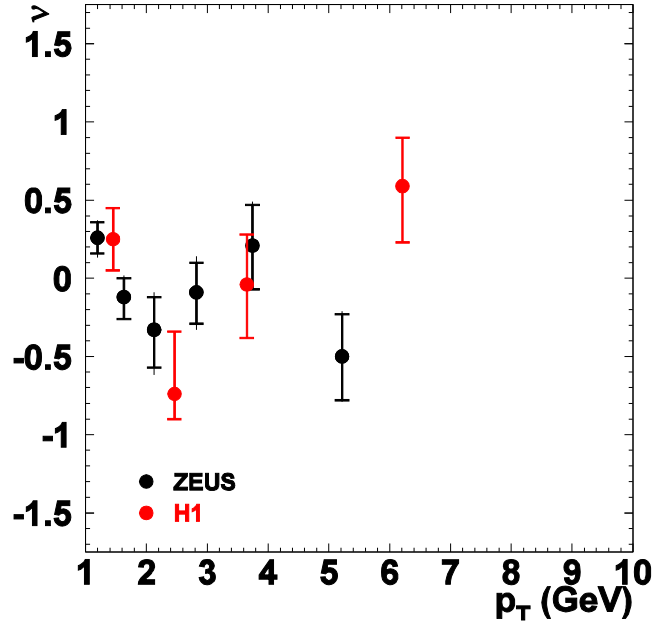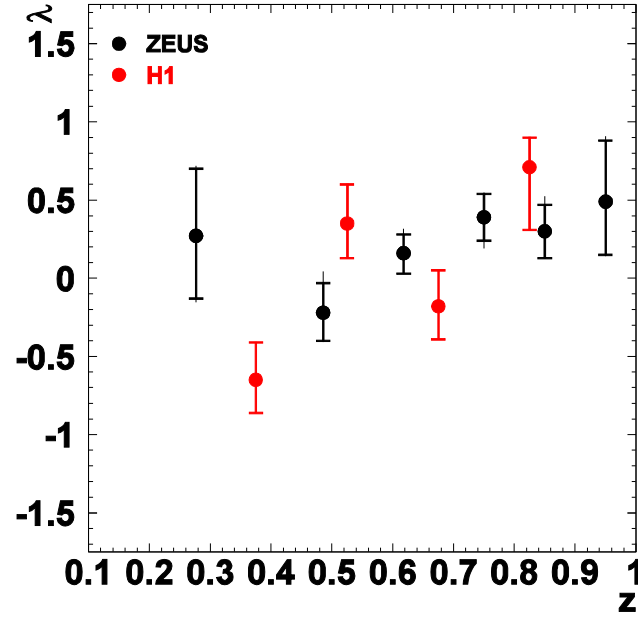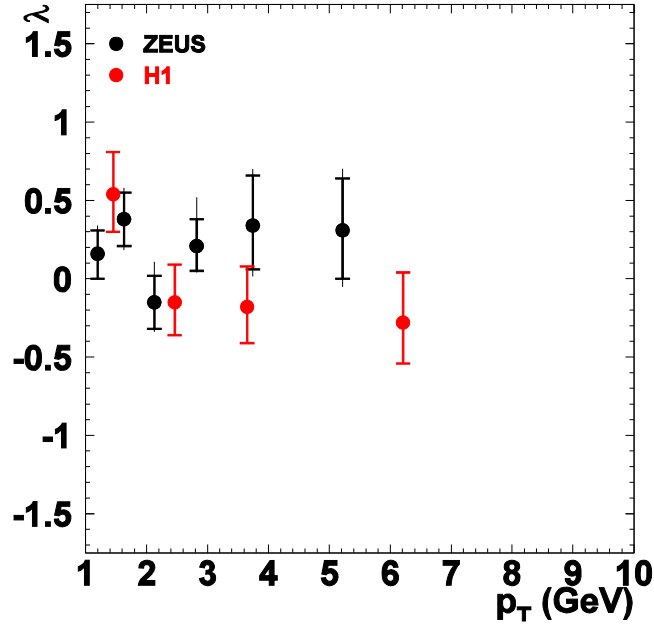❑ x and y axis: chosen to complete a right-handed coordinate system in the *J/ψ* rest frame according to some conventions we were given by the theorists

❑ θ: angle between the μ^+ vector in the *J/ψ* rest frame and the z axis
❑ φ: azimuthal angle in the x-y plane of the μ^+ vector in the *J/ψ* rest frame

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H1: arXiv:1002.0234v1

even if the ZEUS and H1 analyses differ in several details the overall results are compatible

All differences:

- luminosity: ZEUS 468 pb^{-1}, H1 165 pb^{-1}
- W range: ZEUS [50,180] GeV, H1 [60,240] GeV
- pt(J/ψ) > 1 GeV: same for both
- z range for the analysis vs pt(J/ψ) : ZEUS [0.4,1], H1 [0.3,0.9]
for ZEUS the difference between [0.4,1] and [0.4,0.9] in included in the sys. errors

Additional remarks:

- ZEUS requires at least 3 vertex tracks AND some hadronic energy in the forward direction (in the main calorimeter, this alone is equivalent to M_N > 4.4 GeV/c^2)
- H1 requires "only" at least 5 vertex tracks
- for ZEUS as a cross check we tried at least 5 vertex tracks but no significant variation of the results has been found